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Holocene fire on the northeast Tibetan Plateau in relation to climate change and human activity

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ABSTRACT

A series of Holocene charcoal concentrations (CC) records from a slope sedimentary section in Gonghe Basin, northeast Tibetan Plateau, are analyzed to investigate fire characteristics (e.g., frequency or magnitude) and their linkages with paleoclimate change and ancient human activities. The results reveal that changes in fire indicators are well correlated with paleoclimatic change during the past 10.0 ka BP. This pattern is characterized by lower CC in the warm and humid middle Holocene, and higher total CC in the cold, dry climate of the early and late Holocene. Meanwhile, an event characterized by abnormally high CC values at ~3.6 ka BP, distinct from the above trend, indicates an anomalously high fire frequency which cannot easily be explained as the result of a climatic event. Alternatively, this event is noted to correspond closely with the time of rapid human occupation of the high elevation Tibetan Plateau. Many basic domestic and agricultural activities (e.g., slash-and-burn farming, cooking or heating.) have required fire in the hostile environment of the Tibetan Plateau; this is reflected in the higher CC following the spread of human habitation. The analysis of CC might be a useful alternative method for investigating human activities when no direct evidence is available in the Holocene Tibetan Plateau records.

1. Introduction

Fire is one of the important ecological factors for plants, atmospheric chemistry and the global carbon cycle (Filion, 1984; Bird and Cali, 1998; Bowman et al., 2009). As the residual matter of plants burned by fire, charcoals are called the 'fossils of fire', and are regarded as one of the most important proxies in the study of paleofire history (e.g., intensity, frequency etc.) and its relationships with vegetation, ecology and man–land interactions (Filion, 1984; Patterson et al., 1987; Bird and Cali, 1998; Whitlock and Larsen, 2002). In China, several sedimentary materials (e.g., peat, lake and Loess-paleosol sediments) have been used to investigate paleofire processes, paleoclimate, ancestor activities, vegetation types or vegetation cover (e.g., Jiang et al., 2008; Huang et al., 2009; Li et al., 2009; Wang et al., 2013) by means of single or multiple proxies, including elemental carbon (Yang et al., 2001; Zhou et al., 2007), black carbon (e.g., Wang et al., 2012, 2013), taxonomic identification of fossil charcoals (Cui et al., 2002; Li et al., 2012) or charcoal concentrations (Huang et al., 2009; Li et al., 2009). However, these records are primarily located in the low elevation areas of inner China, within or close to the paleo–human activity locations, such as the Loess Plateau and its neighboring region. Few records have been extracted from high elevation areas (e.g., Herrmann et al., 2010; Kramer et al., 2010; Miehe et al., 2014).

The Tibetan Plateau is adjacent to other inland areas which have been key locations for studying past human activities (e.g., Zhang and Li, 2002; Brantingham and Gao, 2006; Kramer et al., 2010; Aldenderfer, 2011; Dong et al., 2012, 2013; Brantingham et al., 2013; Marlon et al., 2013; Tang et al., 2013; Leipe et al., 2014; Miehe et al., 2014; Chen et al., 2015; Yu et al., 2015). At the same time, the northeast part of the Tibetan Plateau is also a key boundary between the monsoon region and inner arid region (Bryson, 1986). The first charcoal study in this area will offer a unique chance to investigate the paleofire history, and to discover its linkages with paleoclimate change and human activities. In this

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study, firstly we introduce the CC records found on the northeast Tibetan Plateau; then we compare these with the Holocene climate change record to discuss underlying relationships; finally we analyze anomalies in the CC records to investigate their linkages with human activities.

2. Study site

The KE section (35°38.7130′ N, 101°06.0050′ E, 3780 m a.s.l.) is located at the southeastern edge of the Gonghe Basin, northeast Tibetan Plateau (Fig. 1A). The Gonghe Basin covers an area of 13,800 km^2, surrounded by Xiqin Mountain to the east, Heka Mountain and Wahong Mountain to the south and southwest, the Qinghai south Mountain to the north (and the adjacent Qinghai Lake), and the Laji Mountain to the northeast (Dong et al., 1993) (Fig. 1B). The area has a typical cold arid to semi-arid continental climate, the mean annual temperature is between ca. 1.0 °C and 5.2 °C, and the mean annual precipitation ranges from ~400 mm in the southeast to ~310 mm in the northwest, of which approximately 70% comes from monsoonal rainfall during the summer (Xun and Li, 1987). Small lakes and rivers are distributed across the central and southeast basin, interrupted by some mobile, semi-fixed and fixed sand dunes (Fig. 1B). On the slopes and terraces of the southeast basin, dust storms and sediment deposition often occur in winter and spring due to the high frequency of strong winds (Dong et al., 1993). Typical steppe, desert steppe and cold steppe vegetation is present, dominated by *Stipa krylovii* (*Orinus-thoroldii*), *Sarracenia purpurea* and *Caragana tibetica*. In addition, *Artemisia arenaria*, *Agriophyllum squarrosum* and *Iris lactea* var. *chinensis* occur along the rivers and in the deserts, while some bryophytes can develop on the alpine slopes (Zhou et al., 1987).

3. Materials and methods

3.1. Lithostratigraphy and chronology

The 410 cm-thick continuous slope sediments of the KE section, extracted from the northern gully of Xiqin Mountain, consist of the sod horizon (meadow), paleosol, peat-like and peaty Loess-like deposits (Fig. 2A). The sediments are mainly wind transported and are derived from the upwind sand dunes (for details see Liu et al., 2013).

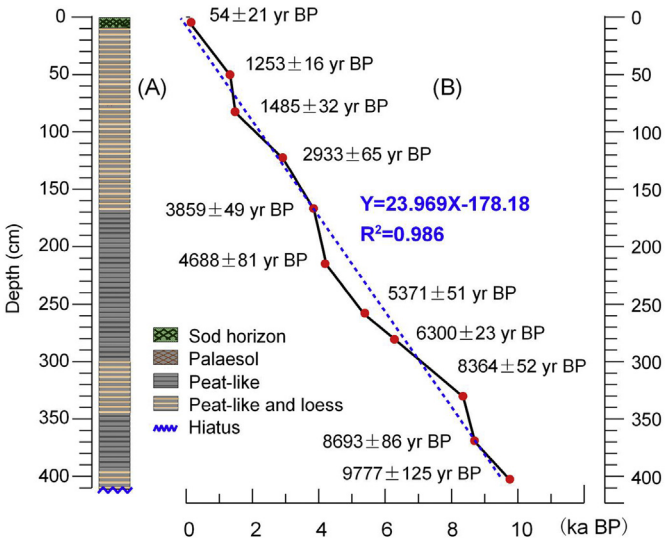

Fig. 2. (A) Stratigraphic framework and (B) age-depth model of the KE section.

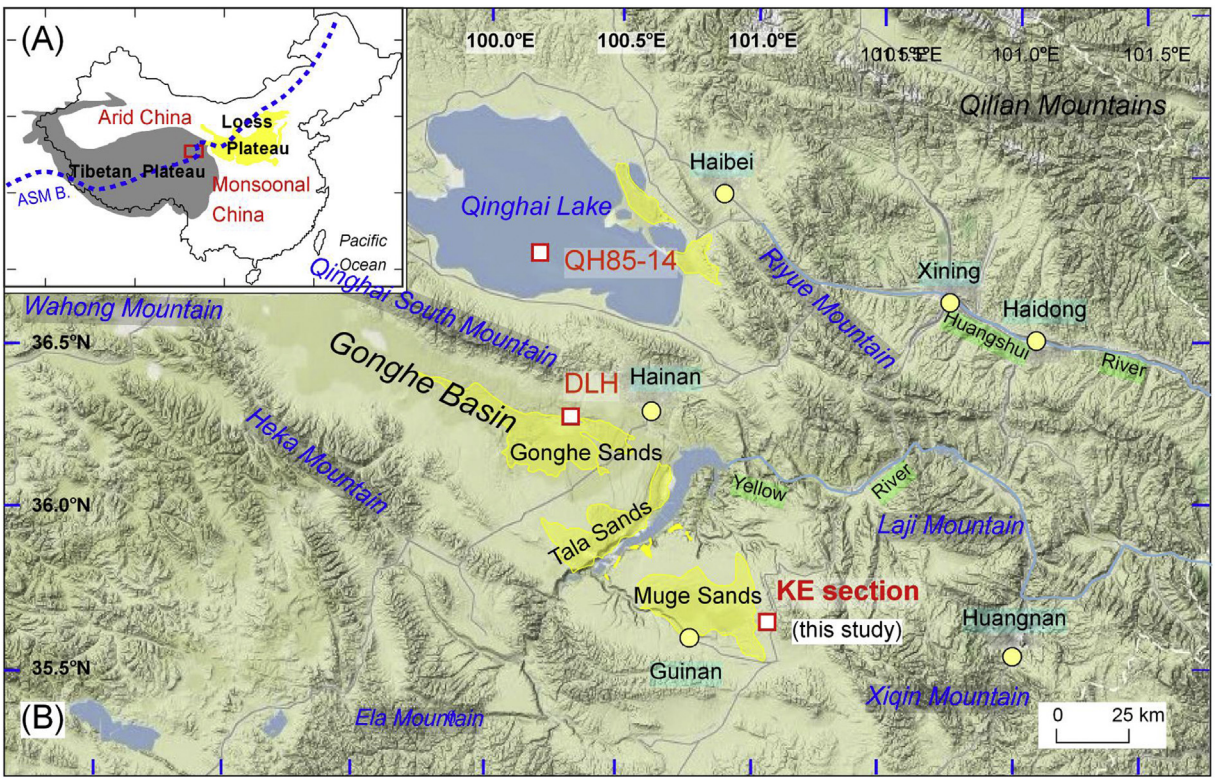

Fig. 1. (A) Location map (ASM B.: Asian summer monsoon boundary) and (B) KE section in the Gonghe Basin (Holocene pollen study cores: GH85-14 (Shen et al., 2005) and DLH (Cheng et al., 2010)).

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